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Compact Strip Production (CSP) : the approach for economical production of hot wide strip*

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This paper presents the Compact Strip Production (CSP) process technology. It describes the plant of Nucor Steel Corp. at Crawfordsville and the operating sequence. Then the results are underlined regarding production, operating costs, and quality. Future expectations are mentioned.

■ INTRODUCTION

The 1989 commissioning of the first CSP production plant at Nucor Steel Corporation, Crawfordsville, has set the market for hot rolled flat products in motion (*fig. 1*). The sufficiently evidenced economical benefits of this process enable a considerable reduction of the market prices while maintaining reasonable profits, and thereby generate a noticeable competitive pressure on the integrated steelmaking plants producing by the conventional method. Hence Nucor Steel Corp. have installed and commissioned a second plant in Hickman, Arkansas. SMS Schloemann-Siemag AG, the suppliers, have already succeeded in booking orders for another six complete plants with a total of eleven casting machines.

Now the question is what exactly makes this novel technology so undisputably successful. The most essential aspects of this question shall be handled in the following.

■ BASIC PRINCIPLE OF THE CSP TECHNOLOGY

The CSP process includes just three technological steps :

The first step is the CSP caster (*fig. 2*) featuring the patented funnel-shaped expanded mould which permits to cast a 50 mm thick thin slab using submerged nozzles which are dimensioned for long service lives. The strand guide follows the principle of a vertical bending machine offering the advantage that no stresses due to asymmetry are imparted to the strand shells. Moreover, any deformation of the strand skin either with liquid or solid core is avoided. Cooling grids and supporting rollers exclusively serve to support and guide the strand.

The production process is simple and clear and ensures that equipment susceptibility to trouble and wear are minimized. Apart from the higher casting speed which is about 5.5 m/min during production, the operating know-how substantially conforms to that of conventional slab casters.

The second step is the soaking furnace (*fig. 3*) with preceding shear for thin slab cutting. This furnace is preferably provided in the form of a roller hearth furnace and serves to tune the production speeds of caster and rolling mill, to equalize the temperature over material thickness, width and length, as well as to reheat the thin slabs in case of operational casting speed reductions or on caster start. In addition, this furnace serves as buffer while roll changes are under way so that both scheduled and unscheduled roll changes can be made in the downline rolling mill without interrupting the casting process. Another downstream dividing shear is suggested optionally. It serves for thin slab dividing if, owing to a malfunction in the rolling mill, the buffering capacity of the soaking furnace should not be sufficient.

* *Subject of lecture at the ATS Steelmaking Conference 1993 (Paris, 15-16 December 1993, Session 1).*

Le procédé CSP pour la production économique de larges bandes à chaud

W. Rohde (SMS)

La production compacte de bandes, avec son abréviation maintenant bien connue dans le monde entier de CSP, est un nouveau procédé pour une production économique de larges bandes à chaud et, sans aucun doute, on peut la considérer comme une découverte capitale.

Le procédé CSP comprend tout juste trois étapes techniques :

La première étape est la machine de coulée CSP avec sa lingotière allongée en forme d'entonnoir qui permet de couler des brames minces de 50 mm d'épaisseur avec des busettes immergées, dimensionnées pour de longues durées de vie. Le guidage de la ligne suit le principe d'une machine de coulée verticale avec cintrage, ce qui offre l'avantage de ne répercuter aucun effort dû à l'asymétrie sur la peau de la brame.

La seconde étape est le four d'égalisation précédé d'une cisaille de coupe à longueur des brames minces. Ce four est de préférence conçu comme un four à rouleaux ; il sert à synchroniser le procédé de production basse vitesse de la machine de coulée et le procédé de production grande vitesse du laminoir et il égalise la température. De plus, ce four sert de tampon pendant les changements de cylindres, qu'ils soient programmés ou non, ce qui permet d'exécuter ces opérations sans perturber la coulée.

La troisième étape est le laminoir avec décalaminage haute pression, table de refroidissement à rouleaux et bobineuse. L'opération de laminage se fait à vitesse constante. L'augmentation de température nécessaire dans les trains classiques n'a plus lieu d'être, et les marques de glissières des fours à brames sont évitées. La simplicité, l'économie et la fiabilité opérationnelle du procédé entraînent des dépenses de fonctionnement plus faibles pour transformer l'acier liquide en bobine de large bande laminée à chaud ; le gain est de l'ordre de 40 % par rapport aux procédés classiques. Ces gains peuvent être principalement attribués au niveau vraiment très bas de dépense énergétique, de perte de matière et de puissance électrique.

Avec la mise en service de la première usine de production CSP, en 1989, chez Nucor Steel Corp. à Crawfordsville/Indiana, USA, le marché des produits plats laminés à chaud a été agité. Les bénéfices clairement mis en évidence sur le plan économique par ce procédé ont permis de réduire considérablement le prix de marché tout en conservant un niveau raisonnable de profits et, de ce fait, provoquer une pression concurentielle notoire sur les aciéries intégrées qui produisent par la filière classique.

Nucor Steel Corp. a implanté et mis en service une deuxième usine à Hickman, Arkansas. Dans le carnet de commande du fabricant, SMS, on peut déjà trouver, à mi-1993, les commandes pour huit usines complètes avec, au total, treize machines de coulée.

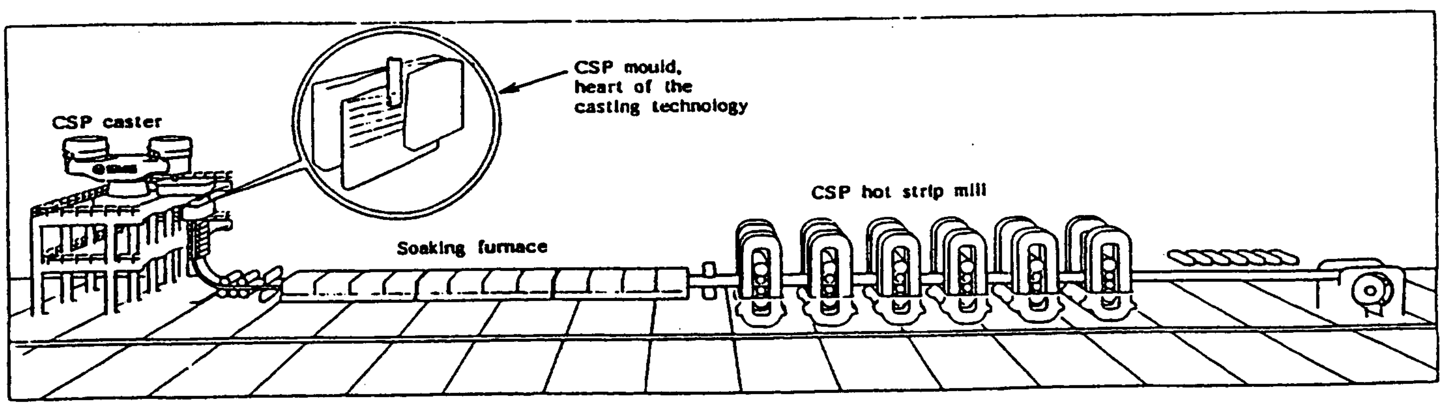


Fig. 1 – CSP technology : basic principle.

Fig. 1 – Procédé CSP : principe de base.

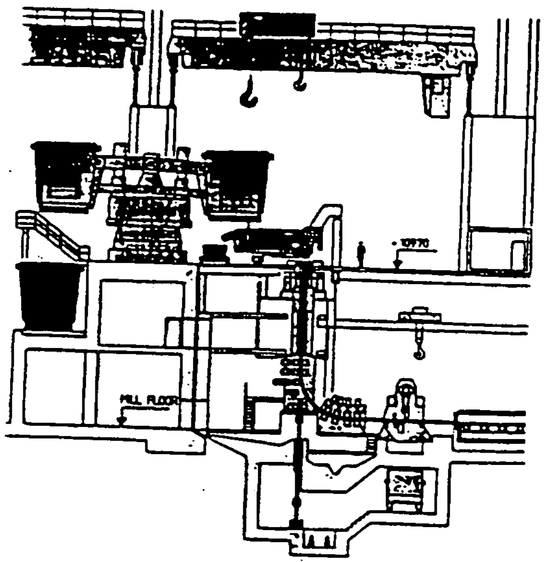


Fig. 2 – CSP caster Nucor II.

Fig. 2 – Machine de coulée CSP pour Nucor II.

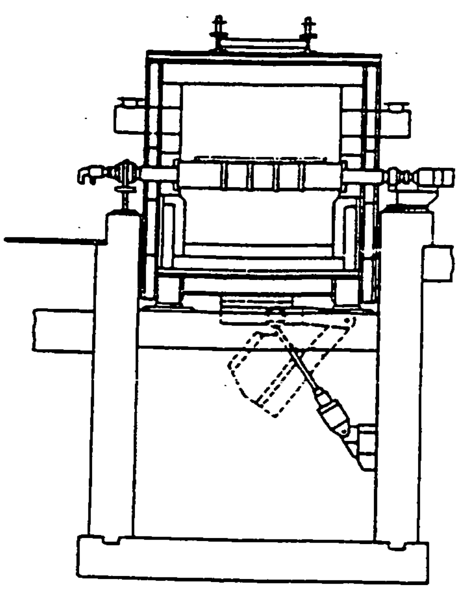


Fig. 3 – Section through furnace : device for scale removal.

Fig. 3 – Coupe transversale du four : équipement de décalaminage.

In stationary operation, the heat content of the ingoing thin slab substantially conforms to that required on leaving the furnace. The thermal energy to be fed to the normally gas-fired soaking furnace just serves to compensate heat losses due to waste gas, convection and roller cooling.

Operation and maintenance of the soaking furnace are absolutely no problem. Its investment costs contribute just insignificantly to the overall investment. The required furnace length – abt. 100 m for single-strand facilities and about 200 m for multi-strand facilities – technically separates the liquid steelmaking area from the rolling mill area which is desirable for other reasons, too.

The third step is the rolling mill *(fig. 4)* with high-pressure descaler, cooling roller table and coiling station. The rolling process reveals a very specific feature of the CSP technology which automatically results from the soaking furnace. The thin slab runs through the distance from soaking furnace to first mill stand at the same speed at which it enters the first stand. Thereby, temperature losses due to radiation and high-pressure descaling are kept constant over the full length of the slab. The roller hearth furnace producing a constant temperature over the slab length with a tolerance of less than 10 °C, the material features a constant temperature from head to tail in all stands of the finishing mill. Rolling is a constant speed. The temperature speedup necessary in conventional mills is not needed and skidmarks produced in conventional mills by slab deposition in the slab surface are avoided. Furthermore, the rolling forces are constant over the full length of the strip *(fig. 5)*. Moreover, the torques do not contain any acceleration torques as involved in conventional mills owing to the speedup and speeddown required for maintaining a constant finish rolling temperature. The available gauge and profile control systems hence do allow to achieve closest thickness tolerances and the most uniform and constant profile values ever obtained in hot wide strip mills.

Simplicity, operational reliability and economy of the plant concept contribute to the low operating costs of 36.5 US$ per short ton needed for converting liquid steel into a hot strip coil *(fig. 6)*. Based thereon and when adding starting material costs, melting costs and depreciations, the total production costs are 224 US$ per short ton. Striking are the low costs for material losses and energy demand.

A comparison between the production costs of a conventional plant and those of the Crawfordsville plant is shown on the *figure 7*.

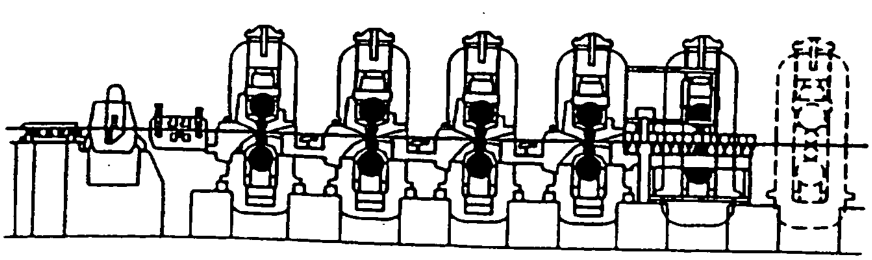


Fig. 4 – CSP rolling mill Nucor II.

Fig. 4 – Laminoir CSP de Nucor II.

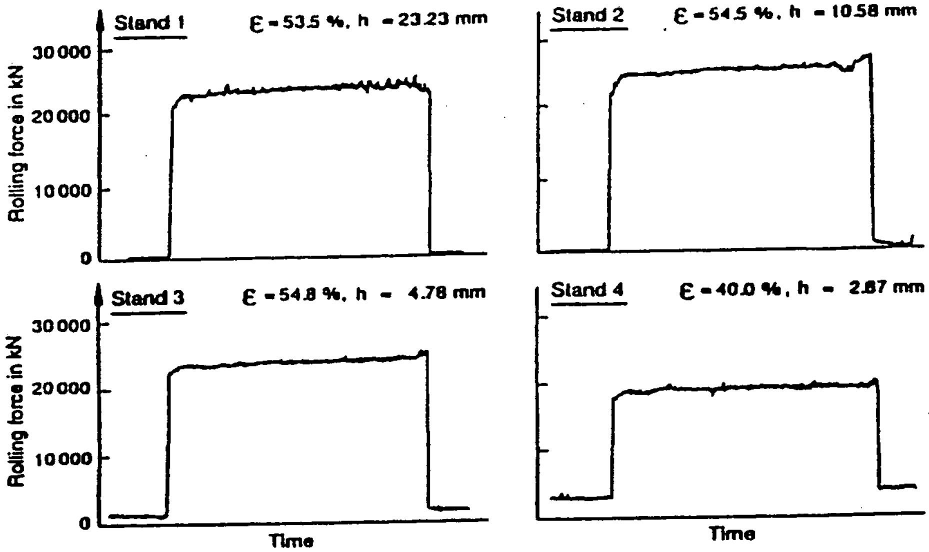
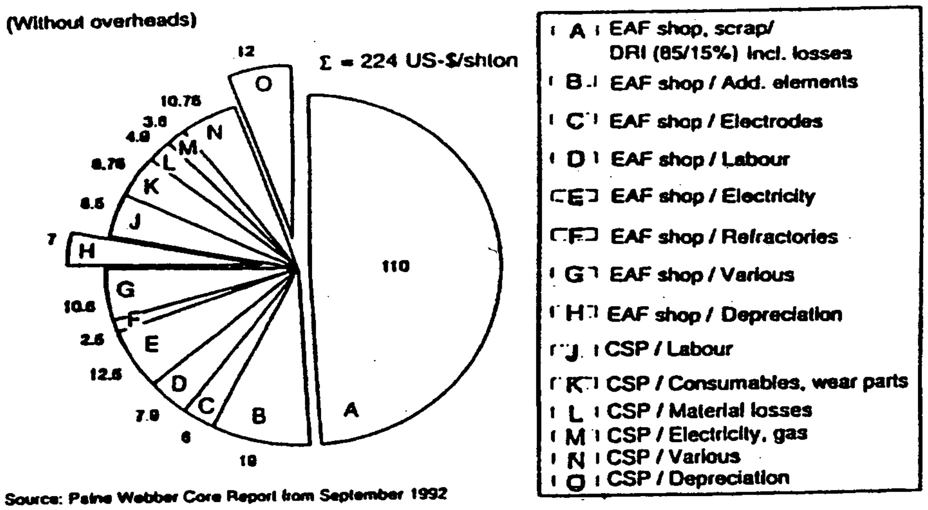


Fig. 5 – Dimensional accuracy of CSP hot strip. Rolling force behaviour (rolling of 50 x 1 260 mm² to 2.87 x 1 260 mm²).

Fig. 5 – Précision dimensionnelle du train à bandes CSP. Comportement de la force de laminage (laminage de 50 x 1 260 mm² à 2,87 x 1 260 mm²).



Source: Paine Webber Core Report from September 1992

Fig. 6 – Nucor Steel Corp., Crawfordsville : breakdown of production costs.

Fig. 6 – Nucor Steel Corp., Crawfordsville : décomposition des coûts de production.

In the CSP technology, material losses are limited to just one crop cut of about 0.5 m each at the beginning and end of a sequence. This means that for a 6-heat sequence, just 0.6 %, of the material used are lost. Undoubtedly, this results represents the absolute minimization of crop losses.

The extremely low energy expenditure of 3.6 US$/short ton of gas energy for the entire production process from liquid steel right up to coiled hot strip is attributable to the consistent observation of the fundamental requirement that the entire thermal energy needed for the process should be provided from the heat contained in the liquid steel. This fundamental demand indeed could be fulfilled almost 100 % (*fig. 8*). All that is added in the soaking furnace is 7.17 % and/or 26 kWh/t in the form of gas energy. Apart from slab reheating by 20 °C, this energy is utilized to compensate waste gas losses, wall losses and roller cooling. The electric energy needed for rolling a 50 mm thick thin slab down to a final thickness of for instance 2.8 mm is 11.84 % of the thermal energy of the liquid steel or 43 kWh/t. This clearly shows the savings in rolling energy achievable due to omission of the roughing mill.

■ THIS FIRST CSP PLANTS IN PRODUCTION

The first CSP production plant for Nucor Steel Corp. in Crawfordsville was built in full compliance with the just described fundamental elements of the CSP technology as single-strand facility with just four mill stands (*fig. 9*). For strip widths of up to 1 350 mm, it was possible to roll low-carbon grade steels down to a final thickness of 2.5 mm. Meanwhile, a 5th mill stand has been set up and commissioned which allows the final thickness to be reduced even further.

The good technical and economical results induced Nucor to set up a second CSP production plant in Hickman, Arkansas/USA which was commissioned in August 1992 after a construction time of just 15 months. Right from the start, this plant was designed to allow an extension to two casting strands. The technology of the production process

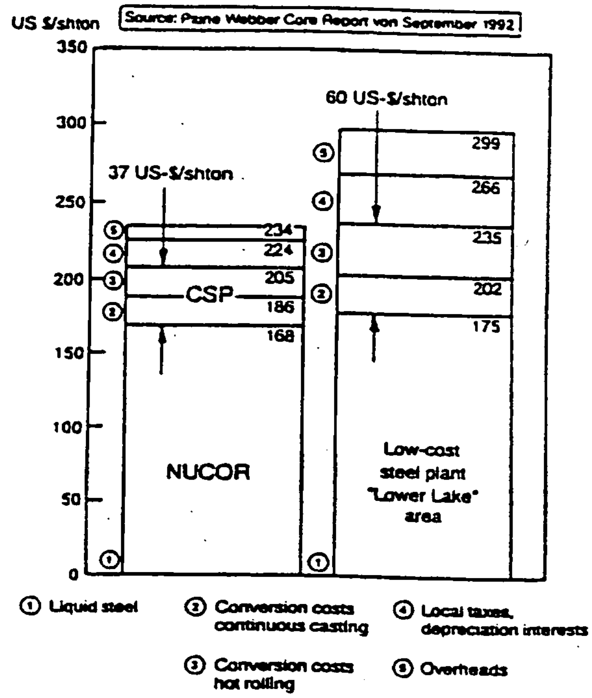


Fig. 7 – Comparison of costs between CSP technology and conventional plant.

Fig. 7 – Comparaison des coûts entre une usine de technique CSP et une usine classique.

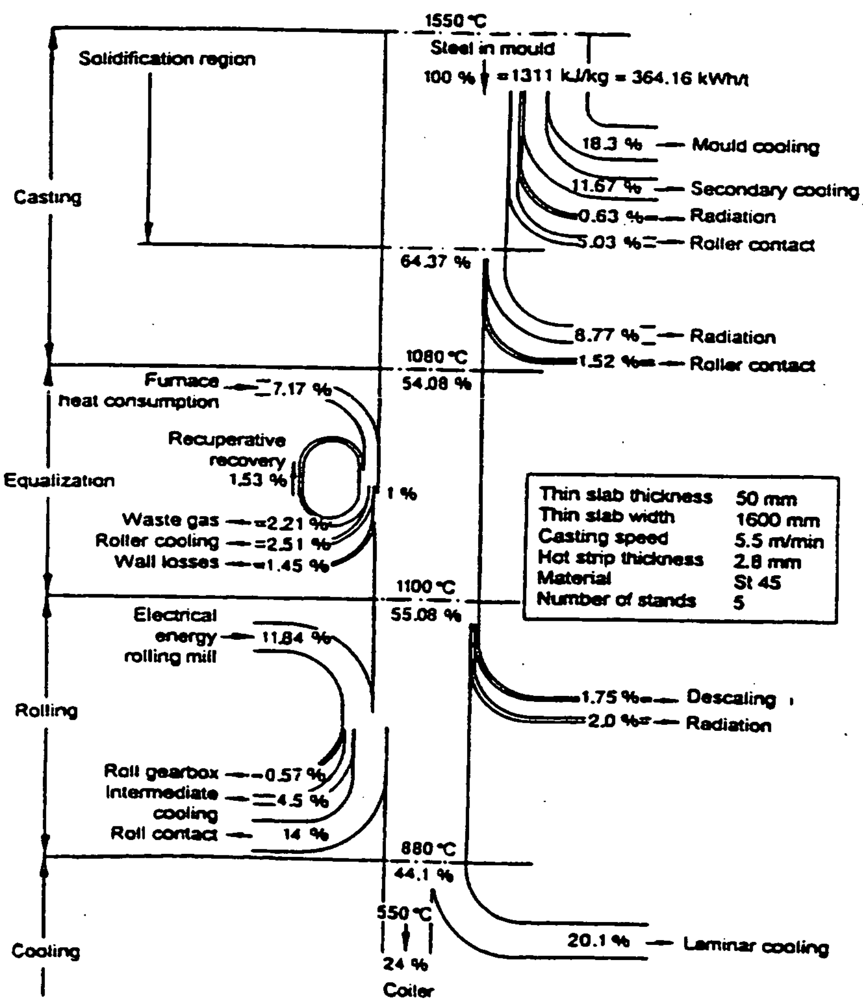


Fig. 8 – CSP technology : temperature balance in a single-strand plant.

Fig. 8 – Procédé CSP : bilan énergétique dans une installation à une seule ligne.

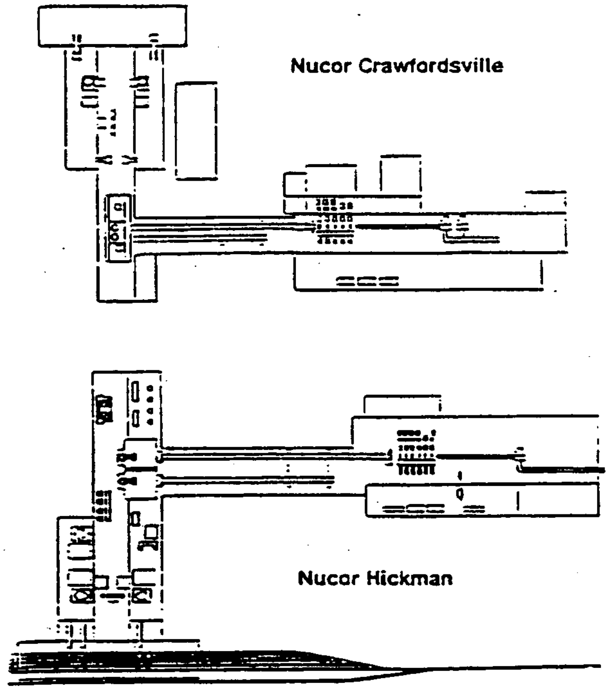


Fig. 9 – CSP plant layouts.

Fig. 9 – Schémas d'installation CSP.

conforms to that of the Crawfordsville plant. The only modifications compared to that first CSP plant reside in the plant's dimensions as well as in some design details. The max. strip width was increased to 1 560 mm. The min. final thickness for low-carbon grade steels is 1.95 mm. To achieve this in view of the unchanged ingoing material thickness of 50 mm, a total of six finishing stands are provided.

The decision to extend the Hickman plant by a second casting strand has meanwhile been made. At about the same time, Nucor Steel Corporation decided to convert their Crawfordsville plant suitable for production on two casting strands, too. The second strands of both plants are scheduled to be commissioned in July 1994.

Thanks to the experiences gained with the Crawfordsville plant, the commissioning time of the Hickman facility could be markedly reduced *(fig. 10)*. The target production was for the first time achieved as early as in April 1992, in other words just 9 months after startup.

Technical data concerning the Crawfordsville and Hickman CSP plants are given on *table I* for melting casting and on *table II* for the furnace and the rolling mill.

The monthly production of the Crawfordsville plant could be increased constantly. After more than 4 years of operation, it is now markedly above the target on which the design of the plant had been based.

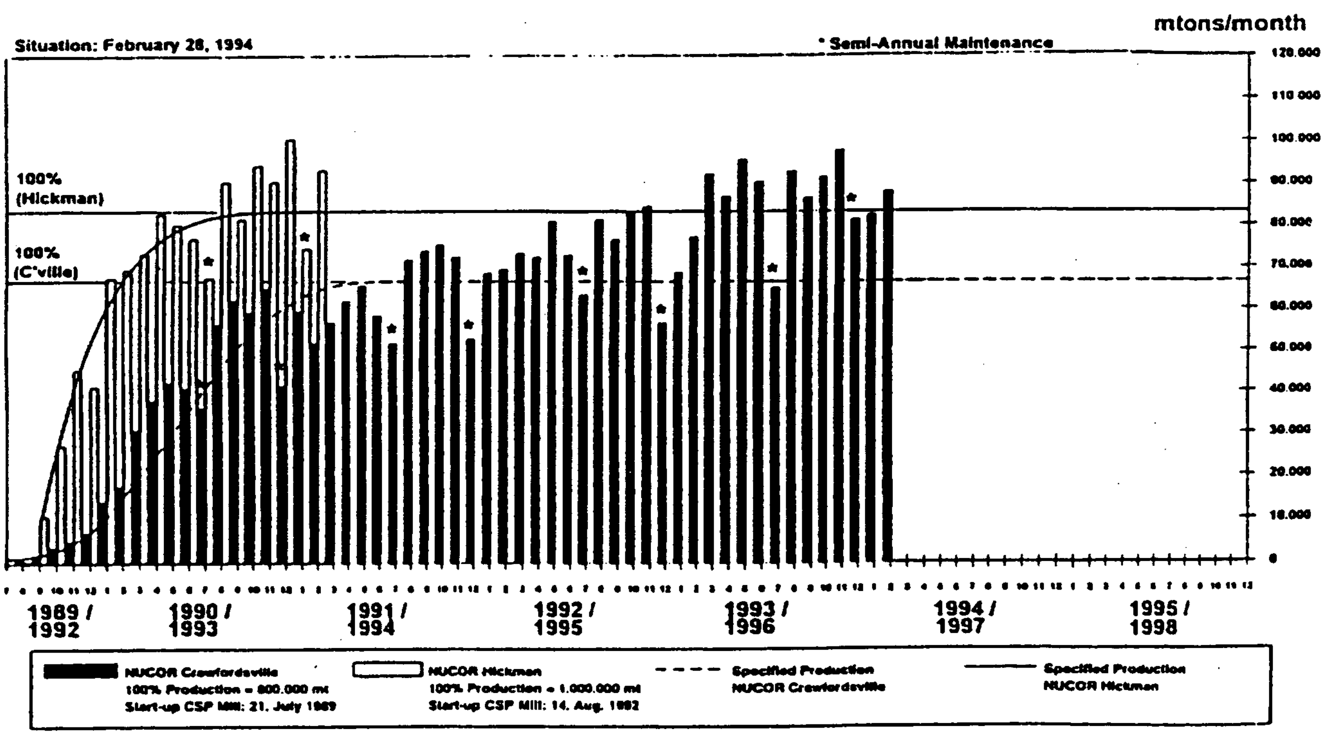


Fig. 10 – Monthly production of hot rolled coils : comparison of Nucor Crawfordsville and Nucor Hickmann.

Fig. 10 – Production mensuelle de bobines laminées à chaud : comparaison entre Nucor Crawfordsville et Nucor Hickman.

Table I : Technical data on melting and casting in the Crawfordsville and Hickman CSP plants.

Tableau I : Données techniques sur l'élaboration et la coulée dans les usines CSP de Crawfordsville et Hickman.

		Nucor Crawfordsville	Nucor Hickman
Melt shop	Electric arc furnaces	2 (AC)	2 (DC)
	Ladle furnaces	2	2
	Vacuum degassing unit	1	–
	Charge weigth	112 t	135 t
	Tap-to-tap time	Minimal 60 min	Minimal 60 min
	Steel types	Plain carbon, general structural and drawing steels	Plain carbon, general structural and drawing steels
CSP caster	Type	Vertical bending machine	Vertical bending machine
	Number of strands	1	1
	Thin slab thickness	50 mm	50 mm
	Thin slab width	900-1 350 mm	1 220-1 560 mm
	Ladle handling	Ladle car	Ladle turret
	Tundish capacity	20 t	28 t
	Mould length	1 100 mm	1 100 mm
	Casting speed	2.5-6.0 m/min	2.5-6.0 m/min
	Metallurgical length	5 800 mm	6 020 mm
	Dummy bar	Rigid dummy bar Vertical insertion and withdrawal from below	Rigid dummy bar Vertical insertion and withdrawal from below
	Dummy bar system	1 pinch roller unit Guide rolls Chain drive	3 pinch roller units – –
	Bending radius	3 000 mm	3 000 mm
	Withdrawal and straightening machine	3 pinch roller units	4 pinch roller units
	Thin slab cutting	Pendulum type mechanical shear	Pendulum type mechanical shear
	Thin slab length	47 m	47 m

In the meantime, another eight compagnies worldwide were convinced of the economical efficiency and the product quality of this novel technology *(table III)*. The basic concept featuring the three process steps casting, soaking and rolling without any thin slab reheating, was not abandoned in any of these cases.

■ CSP PLANT LAYOUTS

The basic CSP concept allows a variety of reasonable plant concepts featuring up to three simultaneously operating casting strands *(fig. 11)*. For 2-strand facilities built as such right from the start, it is particularly advantageous to arrange the casting strands offset on either side of the rolling mill. Depending on whether these two strands are fed from one twin caster or from two single casters, either one or two ferries will be needed. In any case, the finish-cut and soaked thin slabs can be taken from the two strands in any desired order and fed to the rolling mill.

For plants to be converted to 2-strand operation at a later date only, a one-side offset arrangement offers itself with however slightly more complex logistics involved.

To allow, in terms of space, a larger flexibility for adaptation to existing production facilities, another version of the CSP 2-strand facility was developed *(fig. 12)*. The feature of this plant type is that the thin slabs are cast in CSP casters, introduced into the soaking furnaces and cut into

Table II : Technical data on the furnace and the rolling mill in Crawfordsville and Hickman CSP plants.

Tableau II : Données techniques sur le four et le laminoir dans les usines CSP de Crawfordsville et Hickman.

		Nucor Crawfordsville	Nucor Hickman
Soaking furnace	Supplier	Stein Heurtey	Bricmont
	Length	158 m	206 m
	Fuel	Natural gas	Natural gas
CSP rolling mill	Emergency cutting	Pendulum-type mechanical shear	Pendulum-type mechanical shear
	Descaler	High-pressure water descaler	High-pressure water descaler
	Rolling mill	5-stand mill	6-stand mill
	Strip thickness	1.95-12.7 mm	1.95-12.7 mm
	Strip width	900-1 350 mm	1 220-1 560 mm
	Coil outside diameter	1 000-1 900 mm	1 000-1 900 mm
	Coil inside diameter	760 mm	760 mm
	Coil weight	18 kg/mm	18 kg/mm
	Work roll diameter	780 mm	800 mm (FA-F3) 735 mm (F4-F6)
	Work roll barrel length	1 700 mm (CVC technology)	1 900 mm (CVC technology)
	Backup roll diameter	1 350 mm	1 350 mm
	Backup roll barrel length	1 500 mm	1 700 mm
	Roll separating force	30 MN (max.)	35 MN (max.)
	Strip cooling method	Laminar cooling	Laminar cooling
	Coiler	2 (1 retrofitted)	1 initially (second unit to be retrofitted in future)
	Coiler type	Downcoiler with step control	Downcoiler with step control

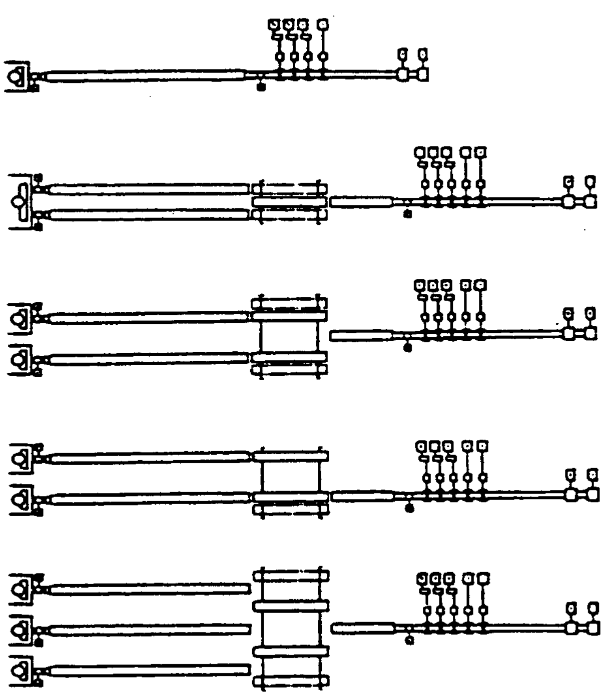


Fig. 11 – CSP plant layouts.

Fig. 11 – Disposition des usines CSP.

lengths conforming to the coil weight. Immediately after temperature equalization, the thin slabs are accelerated to about 2.5 m/s and, after passing through the HP descaler, fed to a non-reversing roll stand. The reductions of 30 to 40 % ensure a complete recrystallization of the microstructure which is a precondition for the subsequent coiling process which takes just 20 to 30 s so that, same as in a conventional coilbox, no major temperature loss occurs. The finished coil is fed to a coil furnace for intermediate storage from where it is then taken, lifted into an uncoiling station and, after another descaling treatment, rolled in the rolling mill.

This plant concept made it possible to adopt the CSP technology also for revamping existing production facilities.

For production facilities having a particularly low annual production such as for production of stainless and acid-resistant steels, a steckel mill offers itself (*fig. 13*). The pro-

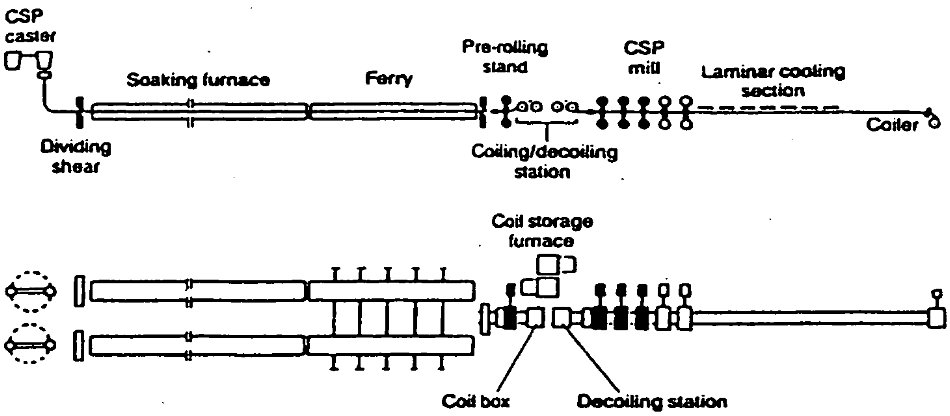


Fig. 12 – Two-strand CSP plant with pre-rolling stand and intermediate cooling.

Fig. 12 – Usine CSP à deux lignes avec cage de prélaminage et refroidissement intermédiaire.

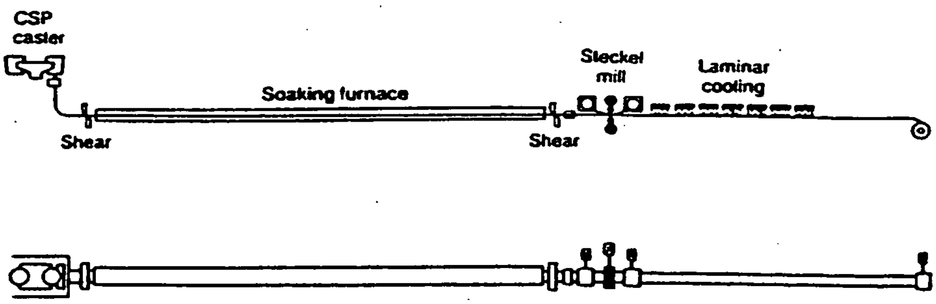


Fig. 13 – One-strand CSP plant with Steckel mill (capacity : 0.4-0.8 million tons/year).

Fig. 13 – Usine CSP à une ligne avec laminoir Steckel (capacité : 0,4 à 0,8 million tonnes/an).

ductions of caster and steckel mill are synchronized through a reduction of the casting speed.

■ CSP PRODUCTS

As just described, the CSP technology is substantially based on the proven know-hows of the continuous casting and rolling mill technologies for direct charging. This means automatically that all material grades cast on conventional slab casters and rolled in hot wide strip mills can also be produced on CSP plants. This has meanwhile also been evidenced in practice by the production and testing of a representative palette of various material grades.

However, the demands of the market do not allow mill users like Nucor Steel Corporation in Crawfordsville or Hickman to give in to some kind of research curiosity and to get into the production of even higher-grade materials. They need to concentrate on the market-demanded large quantities of low-carbon grades for cold reduction *(table IV)* of which more than 4 million tons have meanwhile been produced with excellent mechanical properties and with close tolerances that are beyond those achievable with the present state of technology.

Material grade St 14 was given a particularly critical check *(fig. 14)*. Besides the mechanical properties, the anisotrophy value which is so very important for the deep-drawing process and the hardening exponent were assessed. A comparison of the results with those of conventionally produced hot strip beyond doubt allows the conclusion that the products produced in a CSP plant are equivalent to or even better than those produced by the conventional production technology. Particularly, striking is the minor deviation of all values assessed.

For assessment of the surface quality achieved, five coils from the same test series were, after pickling and cold rolling, divided and carefully selected to quality standard DIN 1623 *(fig. 15)*. The result is impressing as it shows that even the high demand that the automobile industry imposes on the surface quality of DDQ grades is satisfied.

One of the significant preconditions for achieving a good surface quality is that the thin slab surface is perfectly descaled before entering the rolling mill *(fig. 16)*. Since a CSP plant does without the repeated descaling treatments ahead of and in the roughing mill as customary in conventional hot wide strip mills, the demands imposed on the HP descaler ahead of the finishing mill are distinctly higher. The operational experiences gained made it necessary to revise the design of the HP descaler and improved its capacity.

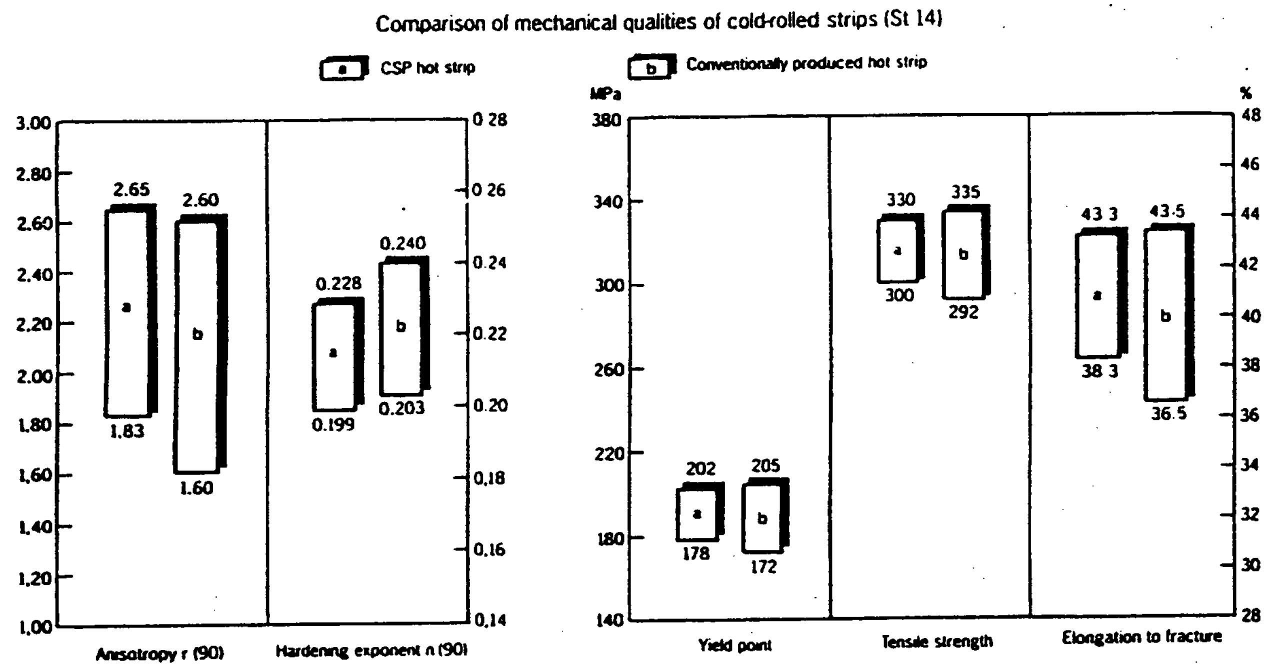
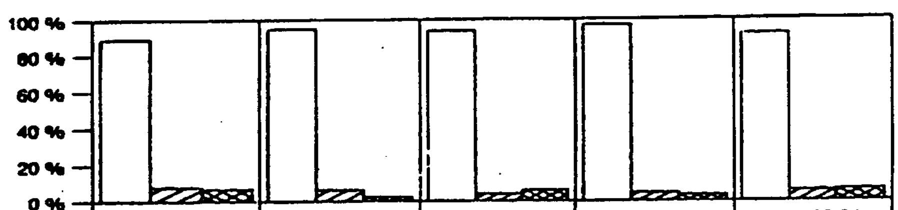


Fig. 14 – CSP quality : mechanical properties of cold rolled strip.

Fig. 14 – Qualité des produits CSP : propriétés mécaniques des bandes laminées à froid.



	12-7362-01	12-7362-05	12-7375-01	12-7375-03	22-6892-04
05/03	89.1	95.1	93.8	97.0	91.9
03/03	5.9	4.3	2.0	1.6	3.8
Second quality	5.0	0.6	4.2	1.4	4.3

Surface quality (top/bottom)

05/03 03/03 Second quality

Steel grade: St14 (hot rolled at Nucor)

Quality standard: DIN 1623 (hand sorting of sheets)

Fig. 15 – Surface quality of cold rolled strip.

Fig. 15 – Qualité de surface de la bande laminée à froid.

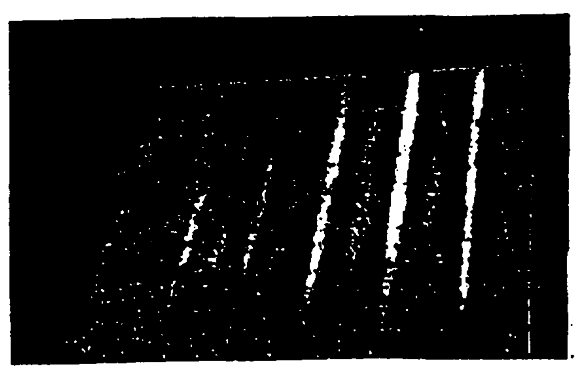


Fig. 16 – Surface quality of the thin slab : perfectly descaled surface.

Fig. 16 – Qualité de surface de la brame mince : surface parfaitement décalaminée.

Table III : CSP plants ; characteristics.

Tableau III : Installations CSP ; caractéristiques.

Customer (Date of order)	CSP caster	CSP mill	Rated capacity, Second phase (t/y)	Slab dimensions (mm)	Min. strip thickness (mm)	Start-up
SMS pilot plant Kreuztal, Germany (1984)	1 strand	-	-	40 -50 x 900 - 1,600	-	October 1985
Nucor Steel Crawfordsville, IN/USA (December 1987)	1st strand	5 stands	800,000	40 - 50 x 900 - 1,350	1.95 (1.6 at 1,100 mm width)	July 1989
(May 1993)	2nd strand		1,800,000			April 1994
Nucor Steel Hickman, AR/USA (Nov. 1990)	1st strand	6 stands	1,000,000	50 x 1,295 - 1,560	1.95 (1.5 at 1,150 mm width)	August 1992
(June 1993)	2nd strand		2,000,000			May 1994
Yieh United Taiwan (September 1989)	2 x 1 strand	6 stands	1,500,000 (2,000,000)	50 x 900 - 1,550	1.95	Not yet specified
Geneva Steel Provo, UT/USA (November 1990)	1 strand combination slab-/CSP caster	-	Not yet specified	150 - 250 x max. 3,200 or 50 x max. 1,880	-	December 1993
Ilva Terni/Italy (September 1991)	1 strand	-	Alloyed, stainless and electrical steel	50 x 1,000 - 1,560	-	December 1992 start of trials
Hylsa S.A. Monterrey/Mexico (December 1992)	1 strand	6 stands	750,000	50 x 790 x 1,350	1.7 (1.2 at 1,140 mm width)	Novembre 1994
Hanbo Steel Pusan/Korea	1st strand	6 stands	1,000,000	50 x 800 - 1,560	1.7 (1.5 at 1,200 mm width)	June 1995
(February (1993)	2nd strand		1,700,000			December 1995
Gallatin Steel Co Warsaw, KY/USA (March 1993)	1 strand	5 stands	1,000,000 (2,000,000)	50 x 1,000 - 1,560	2.1 at 1,250 mm width (St12)	February 1995
Steel Dynamics Inc. USA (LOI November 1993)	1 strand	6 stands	1,200,000	50 x 990 - 1,560	1.6 (1.15 at 1,240 mm)	January1996
Nippon Denro Ispat India (March 1994)	1 strand	6 stands	1,200,000	50 x 900 - 1,560	1.6 (1.2 at 1,150 mm)	August 1996

Table IV : Examples of some typical steel grades produced at Nucor Crawfordsville.

Tableau IV : Exemples de quelques nuances typiques d'acier produites à Nucor Crawfordsville.

AISI	C (%)	Mn (%)	P (%)	S (%)	Si (%)
1005	0.045-0.055	0.25-0.45	< 0.020	< 0.015	< 0.10
1006	0.050-0.085	0.25-0.45	< 0.020	< 0.015	< 0.10
1003	0.050-0.085	0.30-0.50	< 0.020	< 0.015	< 0.10
1010	0.075-0.085	0.30-0.60	< 0.020	< 0.015	< 0.10
1015	0.160-0.184	0.30-0.60	< 0.020	< 0.015	< 0.10
1018	0.165-0.204	0.60-0.90	< 0.020	< 0.015	< 0.10
1020	0.165-0.204	0.30-0.60	< 0.020	< 0.015	< 0.10
1026	0.240-0.280	0.60-0.90	< 0.020	< 0.015	< 0.10
1030	0.270-0.340	0.60-0.90	< 0.020	< 0.015	< 0.10
1050	0.465-0.504	0.60-0.90	< 0.020	< 0.015	< 0.10
Silicon	0.040-0.050	0.40-0.50	< 0.020	< 0.015	0.20-0.30

In the near future : ferritic stainless steel 409.

■ CONCLUSION

The CSP technology is a novel process for economical production of hot wide strip. Its economical efficiency could already be proved for production volumes of less than 1 million tons. It is hence not only suited for integrated iron and steel plants with high productions, but also for small production units of less than 1 million tons per year. This particular characteristic of the novel technology was the key to the fast acceptance on the market and the resultant business success.